# Induction coil Magnetometer LEMI-120

## *User Manual*

LVIV

## Disclaimer notice

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# Contents

# 1. Introduction

The induction coil magnetometer LEMI-120 is intended to be used for the study of magnetic field fluctuations in land conditions, in the frequency band 0.0001-1000 Hz. It can be used both autonomously with any analog registration unit and as a part of a magnetotelluric station. Extremely high sensitivity (Fig.1) ensures excellent signal-to-noise ratio for ground measurements.

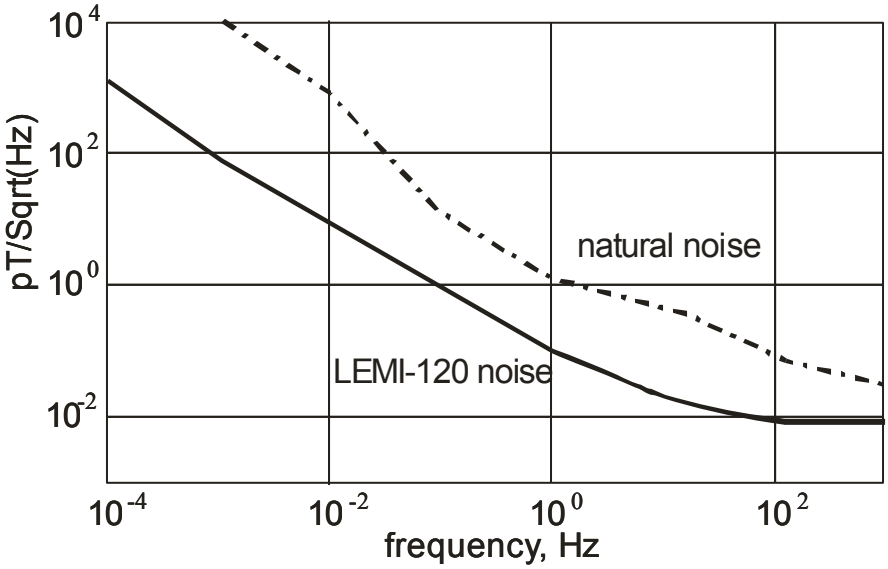


Fig.1. LEMI-120 noise level and natural electromagnetic noise background

Low power consumption and wide power supply range allows for long period measurements at remote sites. A rugged and waterproof housing combined with a waterproof output connector prolong the sensor's active lifetime and ensure overall reliability.

The circuit design and magnetometer construction use several industry specific procedures as well as new technological processes that provide the best possible combination of metrological and operational parameters. Each individual LEMI sensor is experimentally tested and certified.

# 2. Main Technical Parameters

| | |
|---|---|
| Frequency band of received signals | 0.0001 - 1000 Hz |
| Shape of transfer function | linear - flat |
| Transfer function corner frequency | 1 Hz |
| Transformation factor[1] at differential output (pins A and G)<br>at the flat part[2]<br>at the linear part[3] | <br><br>100 mV/nT<br>100* **f** mV/nT |
| Transformation factor error | < 1 dB |
| Magnetic noise level<br>at 0.001 Hz,<br>at 0.01 Hz,<br>at 1 Hz,<br>at 100 Hz | <br>≤ 100 pT/√Hz<br>≤ 10pT/√Hz<br>≤ 0.1 pT/√Hz<br>≤ 0.01pT/√Hz |
| Length of connecting cable | ≤ 200 m |
| Power supply voltage (upper limit recommended) | ± (6…12) V |
| Maximum output voltage | ± 2.5 V |
| Current consumption (nominal) | + 14 mA<br>-10 mA |
| Temperature range of operation | minus 20 …+ 50°C |
| Outer dimensions | l = 1290 mm<br>d = 85 mm |
| Design | Rugged and waterproof |
| Weight | 6 kg |

Notes:

[1] The transfer function experimentally derived values are given in Appendix A.

[2] For frequency band between 1 and 1000 Hz transformation factor remains the same for the measured signal within this frequency band.

[3] For frequency band between 0.0001 and 1 Hz transformation factor depends on the frequency **f** of the measured signal.

# 3. Delivery Set

The magnetometer delivery set includes:

| № | Item | Quantity |
|---|---|---|
| 1 | Induction magnetometer LEMI-120[1] | 3 |
| 2 | Technical Description and Operation Manual | 1 |

[1] NN555 - 557

Fig.2. LEMI-120 induction magnetometers

# 4. Service and Guarantee

4.1. The term of warranty is 18 months after delivery if all requirements of the present instruction such as applied voltage, weather conditions, vibrations and shocks are observed. During this term the manufacturer is liable to repair any defects that may occur through no fault of the consumer or force majeure, or in the event repair is not possible, to change the device by other equivalent specimen.

4.2. The manufacturer will make free service and repair calls to repair the magnetometer as necessary for two years. However, the user must cover the cost of all necessary spare parts and transportation/visit fees.

4.3. The repair time at the manufacturer must be no longer than 45 days.

**Delivery date: 10.07.2014**

V. Pronenko

Signature

All questions as to the magnetometer structure and operation have to be addressed to the designer: pron@isr.lviv.ua – Vira Pronenko.

# 5. Structure and Operation

5.1. The induction coil magnetometer consists of an induction coil sensor and an electronic unit both of which are located inside a common protective housing. The front panel of the magnetometer has a MS3112E12-8S connector for cable coupling.

5.2. The sensor part consists of a magnetic core, the main winding W2 and a magnetic feedback winding W1 (Fig.3). The magnetic core is made of a number of μ-metal tapes, which are insulated one from another and installed inside the protective tube on which both windings are made. A set of electrostatic screens are installed to reduce the interference to a negligible minimum value.

5.3. The electronic unit consists of two circuit boards which are fixed to the internal part of the magnetometer front panel. A simplified functional diagram of the unit is presented in Fig. 3.

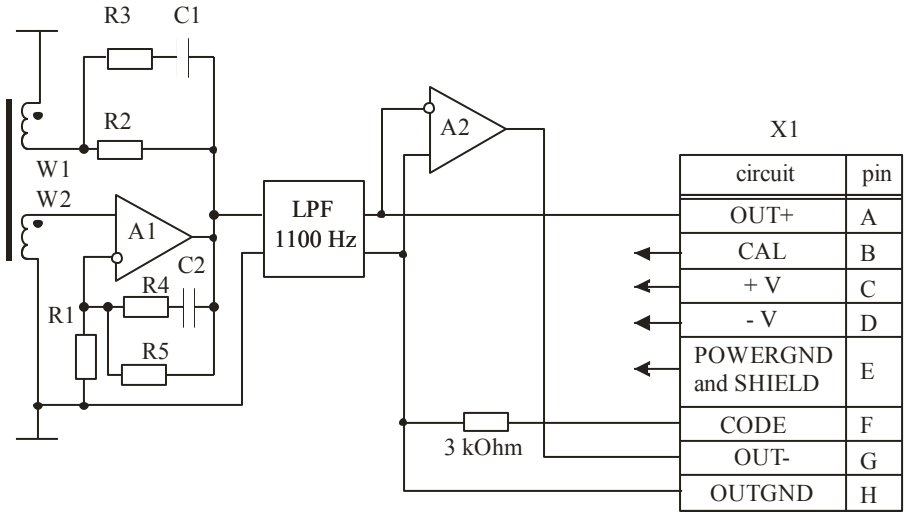


Fig.3. Simplified functional diagram of induction coil magnetometer LEMI-120

The output signal of the main winding W2 is coupled to the input of ultra low-noise modulator-demodulator amplifier A1. The local feedback loop consisting of R1, R4, R5, and C2 of amplifier A1 fixes its total amplification factor at low frequencies to approximately 200.

Output of amplifier A1 through the correction circuit R2, R3, and C1 is coupled to the magnetic flux feedback winding W1. Magnetic and local feedbacks circuits help develop flat part of the transfer function of the magnetometer within the frequency band from 1 to ~ 1000 Hz.

The output of A1 is also connected to a 6-th order LPF filter (1100 Hz cut-off frequency) with a gain of 15. Symmetrical output voltage is formed from the output of inverter A2.

***CAUTION: The A1 amplifier input is protected from damage by overloading signals but not from strong ones, such as nearby lightning!***

5.4. The amplifier A1 was developed using the principle of modulation-demodulation (M-DM). The processing of input signals uses three stages:

modulation of high frequency signal (**$f_m$=6000Hz**) by input low frequency signal (DC to 1000Hz);
amplification of the modulated high-frequency signal;
demodulation of this modulated signal.

**NOTE:** *The amplifier has extremely low noise at the low frequency end, but each M-DM amplifier is sensitive to all signals in the band* ***±1000Hz*** *around the frequencies* ***n*$f_m$****. The LEMI-120 magnetometer suppresses these signals by 40dB, but it is not recommended to use the LEMI-120 in noisy environment with high content of upper frequencies, e. g., close to powerful LF transmitters.*

5.5. A reference signal may be applied to pin B (CAL) of the output connector to test the device. Applying a 10 Hz 5$V_{ptp}$ signal to pin B (with pin H as the return wire) produces output signal about 2 n$T_{ptp}$.

***NOTE: This procedure serves exclusively for IM operation checking. The IM calibration can not be done by giving signals to pins B and H, but only in specialized calibration facility!***

5.6. The external housing of the induction coil magnetometer has a tubular shape and is made of a fiberglas tube with built-in electrostatic screen. The housing is also covered by a protective plastic tube to withstand environmental exposure, shocks and vibrations within allowed limits without damage. The front panel which includes the cable connector, electronic unit and induction coil sensor with all windings can be removed in order to access the housing interior.

**NOTE:** *Opening the sensor housing before the end of the warranty term without written permission from the manufacturer cancels all guarantee obligations.*

# 6. Preparation for Operation

6.1. Read this entire manual, check the delivery set and inspect the exterior or the unit for damages that might have occurred during shipping.

6.2. Couple the sensor to a measuring device and a power supply. See Fig.4 for recommended connection layout.

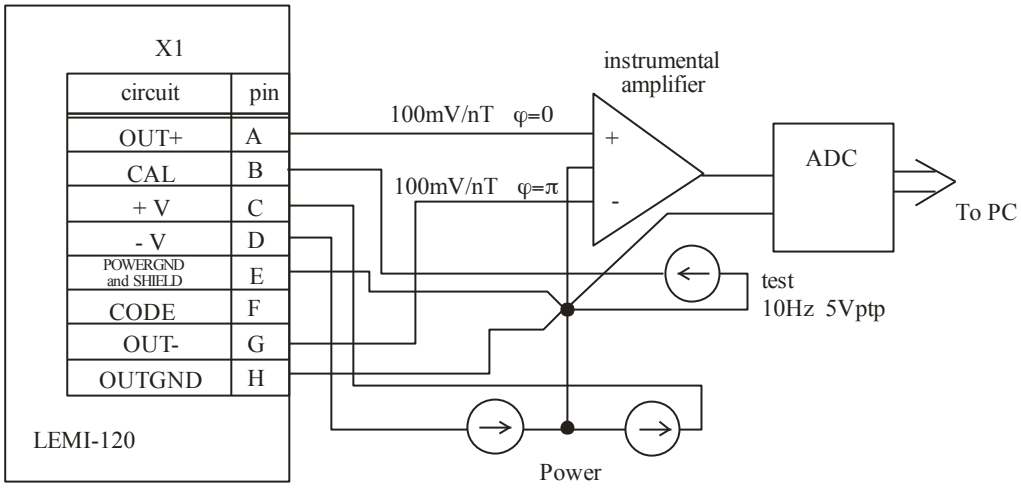


Fig.4. Connection diagram for precise measurements.

***CAUTION: Be careful when connecting the magnetometer to the power supply! The magnetometer is protected from incorrect polarity, but is not protected against overvoltage of power supply!***

6.3. If a performance check is required, then a test signal source must be connected as shown in Fig. 4. In regular operation the mode test signal source must be disconnected.

6.4. The LEMI-120 magnetometer is ready for operation within three minutes after power is applied.

In order to obtain extremely low noise level at the lowest frequency it is recommended to increase the time interval between the installation of the sensor and measurement.

# 7. Utilization and Transportation

7.1. The utilization conditions of LEMI-120 magnetometer are:

| | |
|---|---|
| temperature | -10 $^{o}$C to +50$^{o}$C |
| humidity | up to 100% |
| pressure | 700 to 1100 hPa |

7.2. Although the magnetometer housing is hermetical it is not advisable to expose the device to heavy rain or immerse it in water.

7.3. Avoid shocks to the magnetometer of more than 10 g and vibrations in a frequency band between 1–1000 Hz with accelerations more than 5 g.

7.4. Do not pull the cable to retrieve the magnetometer as the connector or cable can be damaged.

## Appendix A. Transformation factor values

The first column contains frequency in Hz, the following columns contain transformation factor(s) values in mV/nT and phase shift in degrees of angle between input and output signals. Both are measured with error 2 %
For all magnetometers the parameters at 0.0001 Hz, 0.001 Hz and 0.01 Hz are obtained by calculation.

| f, Hz | 0.0001 | 0.001 | 0.01 |
|---|---|---|---|
| S, mV/nT | 0.02 | 0.2 | 2 |
| Phase, ° | 90 | 90 | 89 |

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| f, Hz | S, mV/nT | Phaze, º |
|---|---|---|
| 2.1000E-2 | 1.877E0 | 8.7022E1 |
| 3.1770E-2 | 2.912E0 | 8.8247E1 |
| 4.8062E-2 | 4.403E0 | 8.7471E1 |
| 7.2711E-2 | 6.642E0 | 8.5759E1 |
| 1.1000E-1 | 1.007E1 | 8.4529E1 |
| 1.3249E-1 | 1.234E1 | 8.7859E1 |
| 1.5959E-1 | 1.397E1 | 8.0891E1 |
| 1.9222E-1 | 1.729E1 | 8.0095E1 |
| 2.3153E-1 | 2.063E1 | 7.7175E1 |
| 2.7888E-1 | 2.461E1 | 7.4771E1 |
| 3.3590E-1 | 2.987E1 | 7.1209E1 |
| 4.0459E-1 | 3.551E1 | 6.9186E1 |
| 4.8733E-1 | 4.056E1 | 6.6878E1 |
| 5.8698E-1 | 4.789E1 | 6.1667E1 |
| 7.0702E-1 | 5.490E1 | 5.7426E1 |
| 8.5160E-1 | 6.045E1 | 5.2269E1 |
| 1.0257E0 | 6.870E1 | 4.6523E1 |
| 1.2355E0 | 7.405E1 | 4.1201E1 |
| 1.4881E0 | 8.065E1 | 3.5923E1 |
| 1.7925E0 | 8.575E1 | 3.0723E1 |
| 2.1590E0 | 8.980E1 | 2.6044E1 |
| 2.6005E0 | 9.220E1 | 2.2004E1 |
| 3.1323E0 | 9.475E1 | 1.8258E1 |
| 3.7728E0 | 9.620E1 | 1.4997E1 |
| 4.5443E0 | 9.735E1 | 1.2225E1 |
| 5.4736E0 | 9.820E1 | 9.7740E0 |
| 6.5929E0 | 9.890E1 | 7.5350E0 |
| 7.9411E0 | 9.915E1 | 5.6269E0 |
| 9.5649E0 | 9.945E1 | 3.8884E0 |
| 1.1521E1 | 9.970E1 | 2.2603E0 |
| 1.3877E1 | 9.975E1 | 6.5976E-1 |

| | | |
|---|---|---|
| 1.6715E1 | 9.985E1 | -8.7464E-1 |
| 2.0132E1 | 9.990E1 | -2.4690E0 |
| 2.4249E1 | 9.995E1 | -4.1553E0 |
| 2.9208E1 | 9.990E1 | -5.9520E0 |
| 3.5181E1 | 1.000E2 | -7.9490E0 |
| 4.2375E1 | 1.001E2 | -1.0157E1 |
| 5.1041E1 | 1.008E2 | -1.2756E1 |
| 6.1478E1 | 1.001E2 | -1.6073E1 |
| 7.4050E1 | 1.001E2 | -1.9681E1 |
| 8.9192E1 | 9.980E1 | -2.4092E1 |
| 1.0743E2 | 9.985E1 | -2.9270E1 |
| 1.2940E2 | 9.965E1 | -3.5494E1 |
| 1.5586E2 | 9.940E1 | -4.2906E1 |
| 1.8773E2 | 9.925E1 | -5.1929E1 |
| 2.2612E2 | 9.880E1 | -6.2839E1 |
| 2.7236E2 | 9.810E1 | -7.6053E1 |
| 3.2806E2 | 9.700E1 | -9.2000E1 |
| 3.9514E2 | 9.510E1 | -1.1167E2 |
| 4.7595E2 | 9.185E1 | -1.3544E2 |
| 5.7328E2 | 8.700E1 | -1.6418E2 |
| 6.9050E2 | 8.085E1 | 1.6102E2 |
| 8.3171E2 | 7.530E1 | 1.1756E2 |
| 1.0018E3 | 7.145E1 | 5.2120E1 |

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| f, Hz | S, mV/nT | Phaze, º |
|---|---|---|
| 2.1000E-2 | 1.930E0 | 8.8941E1 |
| 3.1770E-2 | 2.915E0 | 8.8169E1 |
| 4.8062E-2 | 4.412E0 | 8.7295E1 |
| 7.2711E-2 | 6.639E0 | 8.6058E1 |
| 1.1000E-1 | 1.002E1 | 8.4086E1 |
| 1.3249E-1 | 1.225E1 | 8.1622E1 |
| 1.5959E-1 | 1.489E1 | 8.2228E1 |
| 1.9222E-1 | 1.722E1 | 7.9310E1 |
| 2.3153E-1 | 2.045E1 | 7.9072E1 |
| 2.7888E-1 | 2.508E1 | 7.5888E1 |
| 3.3590E-1 | 2.970E1 | 7.2319E1 |
| 4.0459E-1 | 3.356E1 | 7.1409E1 |
| 4.8733E-1 | 4.060E1 | 6.5826E1 |
| 5.8698E-1 | 4.716E1 | 6.1796E1 |
| 7.0702E-1 | 5.504E1 | 5.6888E1 |
| 8.5160E-1 | 6.172E1 | 5.2370E1 |
| 1.0257E0 | 6.874E1 | 4.6557E1 |
| 1.2355E0 | 7.500E1 | 4.1311E1 |
| 1.4881E0 | 8.033E1 | 3.5945E1 |
| 1.7925E0 | 8.565E1 | 3.1042E1 |
| 2.1590E0 | 8.940E1 | 2.6362E1 |

| | | |
|---|---|---|
| 2.6005E0 | 9.208E1 | 2.2085E1 |
| 3.1323E0 | 9.459E1 | 1.8469E1 |
| 3.7728E0 | 9.620E1 | 1.5231E1 |
| 4.5443E0 | 9.730E1 | 1.2367E1 |
| 5.4736E0 | 9.831E1 | 9.8539E0 |
| 6.5929E0 | 9.881E1 | 7.6248E0 |
| 7.9411E0 | 9.920E1 | 5.6951E0 |
| 9.5649E0 | 9.946E1 | 3.9068E0 |
| 1.1521E1 | 9.973E1 | 2.2709E0 |
| 1.3877E1 | 9.985E1 | 7.3379E-1 |
| 1.6715E1 | 9.995E1 | -7.5158E-1 |
| 2.0132E1 | 1.000E2 | -2.4009E0 |
| 2.4249E1 | 1.000E2 | -4.0361E0 |
| 2.9208E1 | 1.000E2 | -5.8204E0 |
| 3.5181E1 | 1.000E2 | -7.8261E0 |
| 4.2375E1 | 1.001E2 | -1.0081E1 |
| 5.1041E1 | 1.004E2 | -1.2757E1 |
| 6.1478E1 | 1.001E2 | -1.5795E1 |
| 7.4050E1 | 1.002E2 | -1.9380E1 |
| 8.9192E1 | 1.001E2 | -2.3748E1 |
| 1.0743E2 | 1.001E2 | -2.8822E1 |
| 1.2940E2 | 1.000E2 | -3.4997E1 |
| 1.5586E2 | 1.000E2 | -4.2373E1 |
| 1.8773E2 | 9.993E1 | -5.1306E1 |
| 2.2612E2 | 9.976E1 | -6.2139E1 |
| 2.7236E2 | 9.939E1 | -7.5310E1 |
| 3.2806E2 | 9.868E1 | -9.1318E1 |
| 3.9514E2 | 9.718E1 | -1.1106E2 |
| 4.7595E2 | 9.425E1 | -1.3503E2 |
| 5.7328E2 | 8.949E1 | -1.6405E2 |
| 6.9050E2 | 8.307E1 | 1.6084E2 |
| 8.3171E2 | 7.695E1 | 1.1710E2 |
| 1.0018E3 | 7.164E1 | 5.1749E1 |

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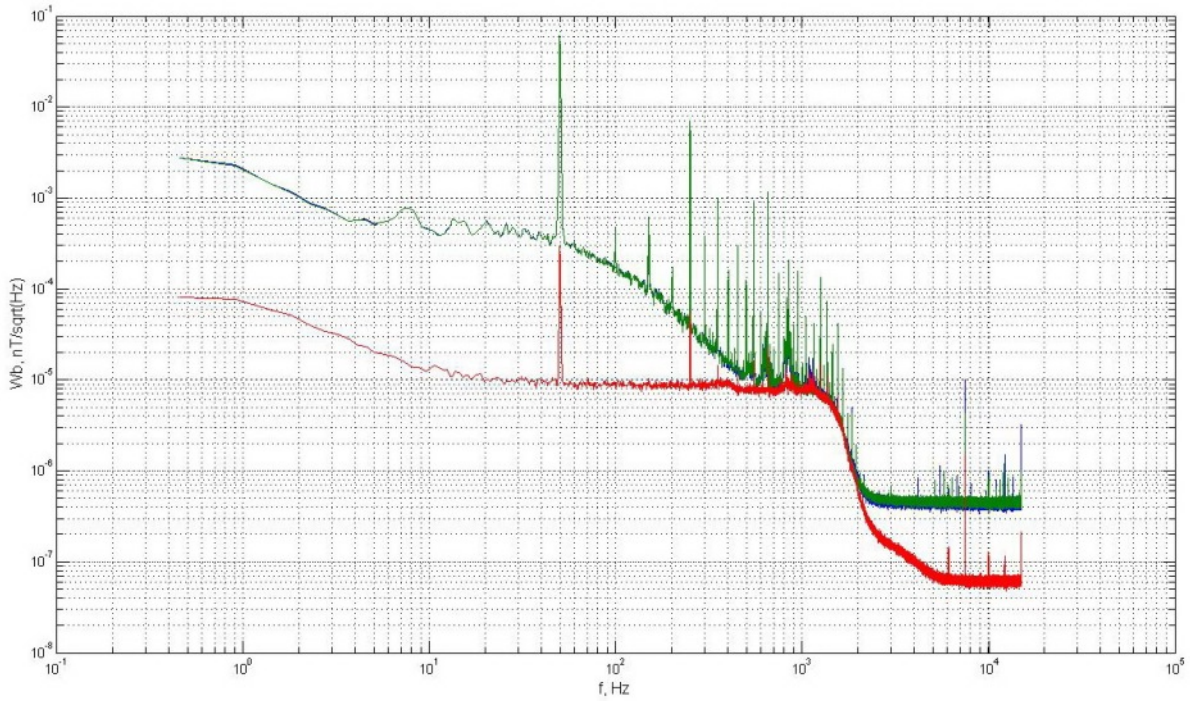
| f, Hz | S, mV/nT | Phaze, º |
|---|---|---|
| 2.1000E-2 | 1.932E0 | 8.8675E1 |
| 3.1770E-2 | 2.911E0 | 8.8336E1 |
| 4.8062E-2 | 4.413E0 | 8.7296E1 |
| 7.2711E-2 | 6.674E0 | 8.6047E1 |
| 1.1000E-1 | 1.003E1 | 8.4029E1 |
| 1.3249E-1 | 1.163E1 | 8.2991E1 |
| 1.5959E-1 | 1.382E1 | 8.2393E1 |
| 1.9222E-1 | 1.772E1 | 8.1144E1 |
| 2.3153E-1 | 2.098E1 | 7.7756E1 |
| 2.7888E-1 | 2.472E1 | 7.5202E1 |
| 3.3590E-1 | 2.983E1 | 7.3010E1 |
| 4.0459E-1 | 3.404E1 | 7.0004E1 |

| | | |
|---|---|---|
| 4.8733E-1 | 4.020E1 | 6.6565E1 |
| 5.8698E-1 | 4.720E1 | 6.2203E1 |
| 7.0702E-1 | 5.434E1 | 5.7369E1 |
| 8.5160E-1 | 6.156E1 | 5.2190E1 |
| 1.0257E0 | 6.860E1 | 4.6901E1 |
| 1.2355E0 | 7.533E1 | 4.1190E1 |
| 1.4881E0 | 8.054E1 | 3.5152E1 |
| 1.7925E0 | 8.557E1 | 3.0944E1 |
| 2.1590E0 | 8.956E1 | 2.5879E1 |
| 2.6005E0 | 9.229E1 | 2.2077E1 |
| 3.1323E0 | 9.443E1 | 1.8114E1 |
| 3.7728E0 | 9.628E1 | 1.5131E1 |
| 4.5443E0 | 9.744E1 | 1.2278E1 |
| 5.4736E0 | 9.820E1 | 9.8185E0 |
| 6.5929E0 | 9.886E1 | 7.5665E0 |
| 7.9411E0 | 9.927E1 | 5.6472E0 |
| 9.5649E0 | 9.972E1 | 3.9459E0 |
| 1.1521E1 | 9.982E1 | 2.2511E0 |
| 1.3877E1 | 9.993E1 | 6.8165E-1 |
| 1.6715E1 | 1.000E2 | -8.7940E-1 |
| 2.0132E1 | 1.001E2 | -2.4179E0 |
| 2.4249E1 | 1.001E2 | -4.0430E0 |
| 2.9208E1 | 1.002E2 | -5.8735E0 |
| 3.5181E1 | 1.001E2 | -7.8606E0 |
| 4.2375E1 | 1.001E2 | -1.0189E1 |
| 5.1041E1 | 1.012E2 | -1.3198E1 |
| 6.1478E1 | 1.001E2 | -1.5833E1 |
| 7.4050E1 | 1.002E2 | -1.9433E1 |
| 8.9192E1 | 1.000E2 | -2.3804E1 |
| 1.0743E2 | 1.000E2 | -2.8866E1 |
| 1.2940E2 | 9.999E1 | -3.5046E1 |
| 1.5586E2 | 9.990E1 | -4.2410E1 |
| 1.8773E2 | 9.982E1 | -5.1371E1 |
| 2.2612E2 | 9.958E1 | -6.2216E1 |
| 2.7236E2 | 9.916E1 | -7.5474E1 |
| 3.2806E2 | 9.711E1 | -9.1584E1 |
| 3.9514E2 | 9.613E1 | -1.1073E2 |
| 4.7595E2 | 9.325E1 | -1.3458E2 |
| 5.7328E2 | 8.854E1 | -1.6344E2 |
| 6.9050E2 | 8.231E1 | 1.6162E2 |
| 8.3171E2 | 7.645E1 | 1.1796E2 |
| 1.0018E3 | 7.176E1 | 5.1974E1 |

## Appendix B. Typical noise spectral density

Noise spectral density was measured in the field by subtraction of output signals of the two magnetometers placed in similar conditions. Green and blue curves are output signals spectra of two LEMI-120 magnetometers. The red curve is noise level of LEMI-120 magnetometer.



## Appendix C. Selecting the measurements site and conditions

**Important! The induction sensors are very sensitive to the mechanical movements and vibrations. It is recommended to follow the advices below in order to realize their full sensitivity.**

1) The measurement should be carried out in electromagnetically clean area and users should take into account possible magnetic signals from, e.g., nearby thunderstorms, solar bursts etc. The sensor should be located as far as possible from mains power lines and large ferromagnetic objects. It is difficult to give accurate recommendations about the distance to them as it depends on magnetic moment of such objects; the maximal distance between the sensors and registration unit should be no more than 200 m (recommended at least about 100 m). For example, we can clearly observe the process of car doors opening and closing at distances of about 25 meters. Do not select measurement sites near large trees - strong wind will produce soil oscillations and consequently sensor vibration. The distances between each of the three sensors in a three-component array have to be not less than 2 meters.
2) Every effort should be made to provide a stable position for the sensor (FYI, only 1" rotation of the sensor in the Earth magnetic field may produce ~250 pT of parasitic signal). In order to ensure a stable position it is necessary to make beds (holes) with concrete walls for permanent installations.

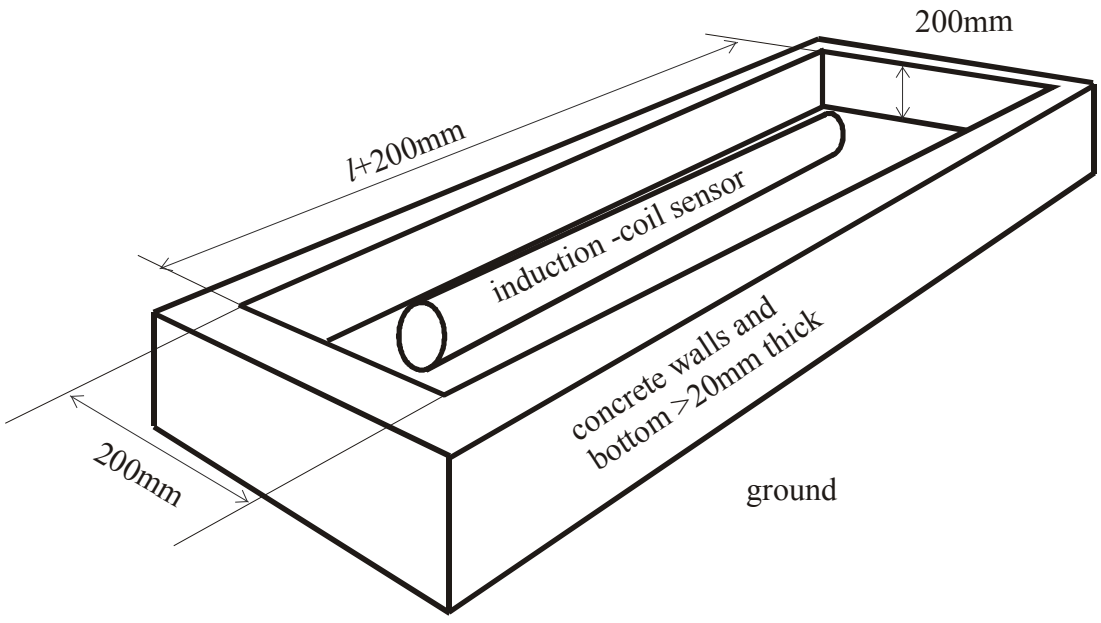



Fig. 5. LEMI sensor permanent installation site

All dimensions of the sensor hole are given for orientation - any deviations in bigger side are possible. The hole has to be covered with any hut against rain and wind, the external dimensions of which have to be at least 20 mm bigger than the hole dimensions. The hut has to be made from non-magnetic and non-conductive material. It is necessary to foresee small gaps between inner part of

the hut and the edges of concrete walls in order to allow the outer air inside freely.
The edges of the concrete walls have to be at least 50-100 mm above the ground level in order to protect from water when covered by the hut.
To avoid water and moisture penetration into connector, we recommend encapsulate connector and adjacent part of the cable (~10-15 cm) together into heat-shrinkage insulation tube.
If there are microseisms supposed in the region it is advisable to fill the concrete bed to half of depth with elastic material such as soft polyurethane, and to put the sensor on top of it, then to press from above by the heavy bag with sand. The first three to five meters of cable connected to the sensor must also be buried.
3) When installing a temporary station it is necessary to bury the sensor in the ground at the depth not less than 2-3 sensor diameters, to pile up about 2-3 cm layer of the sand on the bottom, put then the sensor and press from above by the bag with sand. Such an installation procedure allows for avoiding influence due to blowing wind and decreases sensor temperature fluctuations. If burying the sensor and cable is not possible (e.g., rocky ground) it is advisable that you put the heavy bag with sand on the sensor and cover against the rain.
4) Proceed as follows to connect the sensor to the acquisition system. Prepare a sensor cable, preferably shorter than 200 m, which should contain three twisted wires for the power supply, a shielded twisted pairs for the signal and one wire for analog ground.
5) It is important that a good quality power supply be used, especially when working in high-frequency range. The best way to ensure this is to use a battery placed on an insulating cover such as polyethylene film.
When using DC-DC transformers in the receiving equipment, ensure that they do not produce noise, especially spikes, in their input circuits.
6) Earthing of the analog ground and common power supply lines is necessary and it is advisable that this grounding be made according to "star" system - in one point, using a buried copper stick to connect to it all ground wires together.